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Innovation in flood risk management: An 'Avenues of Innovation' analysis

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Abstract

Innovation in flood risk management (FRM) is a driver for change. Research, however, is sparse in this area, and innovation itself appears to be left largely to chance. This paper uses a 'systems of innovation' approach, defining 'avenues' of innovation, to explore factors that promote or inhibit innovation. The research is based on in-depth interviews with 10 leading figures in FRM in the United Kingdom, and describes the interactions and iterations involved. We conclude that in terms of practice the encouragement of champions should be enhanced, risk cultures require concerted attention to minimise risk aversion, learning should be facilitated, and innovation scaled up to maximise its effectiveness. We aim also to add to the literature on innovation systems, providing a case study of a complex field previously unexplored in this regard. Detailed innovation-encouraging processes here need to be better understood and FRM policies and practices adjusted accordingly.

KEYWORDS

education and training, integrated flood risk management, strategy

1 | INTRODUCTION

Flooding is one of the most significant environmental threats to the United Kingdom (Cabinet Office, 2017; HM Government, 2017). Flood risk management (FRM) in the United Kingdom, as elsewhere (Sayers, Penning-Rowsell, & Horritt, 2017), has undergone 'a major paradigm shift' from simply tackling floodwater as hazard to a more 'strategic, holistic, and long-term approach' (Johnson & Priest, 2008, p. 1; Penning-Rowsell & Johnson, 2015). This approach suggests that the process of innovation has been at work. However, there appears to be a vacuum in terms of understanding in this field, and virtually no research on the subject of innovation in FRM from academic or government circles. Learning what factors inhibit or promote innovation and what are successful innovative processes appears fragmented or even non-existent. Innovation itself appears left largely to chance, despite the significant flood risks that our countries face now and are forecast for the future.

This paper reports on research using a Systems of Innovation (SI) approach (Edquist, 2009) in examining five interrelated FRM topic areas where innovation appears to have been important. Ten key informants have been interviewed, and much relevant documentation consulted, to trace promoting and inhibiting factors affecting innovation. With a better understanding of these issues we can perhaps help to enhance the pace of that innovation and thereby improve further the future management of flood risk in the United Kingdom. We

also hope to add to the large literature on innovation with a case study in a field in which innovation has rarely been researched. Lessons learnt here may also be relevant elsewhere in the world.

2 | INNOVATION, SYSTEMS OF INNOVATION AND 'AVENUES'

Innovation is something original, effective, or revolutionary that has been introduced into and then acknowledged by a market or system (Salter & Alexy, 2013). It appears in many forms (Frankelius, 2009). We judge that innovation does not happen in isolation or via a predetermined path but is characterised by reciprocity and feedback among various components, which determine its ultimate success or otherwise. Rothwell's (1994) fifth successive generation of innovation (Tidd, 2006) is one based on systems integration and such interactions (Figure 1). We acknowledge that there are many definitions and forms of innovation; this is the one we are focusing on, as an evolved form.

2.1 | Systems of innovation

To understand innovation and its processes in FRM in the United Kingdom, it is useful to structure that analysis by employing a conceptual SI Framework, to point to interactions and linkages in the innovation processes, rather than depend on other models of innovation such as linear, coupling, network, parallel, staged, learning and gated (Tidd, 2006); those models do not fully encapsulate the many components and interactions within the complexity of modern FRM. Elements of these other models of innovation processes are important but are seen here as part of the broader SI approach.

Generation	Key Features
First and Second	The linear models – need pull and technology push
Third	Interaction between different elements and feedback loops between them – the coupling model
Fourth	The parallel lines model, integration within the firm, upstream with key suppliers and downstream with demanding and active customers, emphasis on linkages and alliances
Fifth	Systems integration and extensive networking, flexible and customized response, continuous innovation

FIGURE 1 Progress in conceptualising innovation: Rothwell's five generations of innovation models

The SI Framework, defined as 'elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge' (Lundvall, 1992, p. 2), sees innovation processes as interdependent, interactive and non-linear. The components, or actors, within an SI framework are typically divided into organisations and institutions (Edquist, 2009; OECD, 1997). Organisations are the formal structures, such as firms, industries, universities and government agencies whose behaviour is influenced by institutions – laws, rules, norms and routines – that regulate the interactions between the organisations involved (Edquist, 2009). The SI framework relies upon the interactive effect between different components, as they evolve in their 'direction of travel'. We have seen and termed these directions as 'avenues' to emphasis their breadth and heterogeneity (see below).

An SI approach emphasises learning to drive processes of innovation (Lundvall, 1992). Learning 'produc [es] new knowledge or combin[es] existing (and sometimes new) elements of knowledge in new ways' (Edquist, 2009, p. 5) from elements that already exist (Salter and Alexy, 2013). This depends upon repeated interactions between the actors, organisations and institutions in the system, leading to increased productivity (Soumonni, 2013). The combinational power of innovation ushers in the possibility of a domino effect, spurring further innovations or other changes.

Iterative learning therefore needs attention within an SI analysis: the other models generally suggest an 'end' or 'termination' point in innovation (e.g., a product) as the conclusion to a linear and apparently inevitable process. There may be, in this respect, examples of 'isolated' innovations which are not seen as leading to final end points, but these are rare. FRM in comparison is an ongoing and continuous endeavour in the United Kingdom and our SI framework acknowledges the dynamic nature of innovation therein.

2.2 | Avenues

An avenue is 'a way of approaching a problem or making progress toward something' (Oxford University Press, 2017, p. 54). An avenue of innovation is a distinct pathway of evolution that occurs in a systematic manner, an approach first used in a study of technical change and progress in manufacturing (Sahal, 1985). 'Technological guideposts point to the innovation avenues just as the innovation avenues lead to technological guideposts' (Sahal, 1985, p. 71), indicating the iterative and systemic nature of innovation. The avenues are not solutions in themselves but broad routes of evolution and progress

based on continuous feedback and learning. Each can be considered as discrete evolutionary paths, thus allowing innovation within themselves. Some are narrow, some are broad (Sahal, 1985). Considered together, the avenues constitute the various components within the SI Framework, forming the System itself, with its ability to transform discrete innovations in a specific area into innovation of a larger system (in our case, particular innovations affecting the whole field of FRM).

3 | METHODOLOGY

There are three ways to analyse systems of innovation (OECD, 1997): at the level of the firm, by clusters focusing on the interactions between particular types of firms or sectors, and at the national or the international scale. Cluster analysis was chosen here for its emphasis on knowledge flows between different sectors. Clusters interact through 'vertical and horizontal relationships', created through demand, rivalry or knowledge sharing (OECD, 1997, p. 17). This emphasises the importance of feedback loops and the interactive effect of multiple components (Mytelka & Smith, 2002).

Exploratory interviews with two leading authorities in the FRM field were used first, to establish a number of aspects within FRM, seen here as these 'avenues' for innovation (Table 1). More structured interviews with ten FRM experts (including the initial two) obtained their understanding of the processes of innovation within FRM (each interview lasted 1 to 2 hours, employing the questions in Table 2). The interviews were not all recorded but copious notes were taken and quotations logged.

Interviewee choice was partly pragmatic but also designed to cover different elements within U.K. FRM (Table 3). The sample is not large but sufficient to capture a range of views. Gaps are inevitable, such as the privatised water companies, responsible for urban drainage, and organisations such as Flood Action Groups, although our interviewees mentioned neither as important for FRM innovation.

We analyse below examples of innovation cited as significant by our interviewees. To allow some detail we select just three examples per 'avenue', looking in particular for innovation as interactions between and within the different avenues. Within each avenue there should be some congruence or similarity. Between them there will also be links because many innovations have multiple drivers and common actors. We do not attempt to

TABLE 1 The five 'Avenues of Innovation' (the order here is arbitrary, not a ranking)

Measures: This includes structural technologies (traditional engineered flood defenses with dams, levees, by-pass channels that modify the probability of flooding) and non-structural alternatives seeking to manage flooding's consequences with warning systems, spatial planning and insurance arrangements;
Information technologies: the use and development of data and other technologies, including their availability and reliability, to create solutions toward monitoring and estimating flood risk;
Governance and politics: the interplay between local and centralised decision making for funding and planning to modify flood risk;
Resources: skills and capabilities, and also investment and insurance mechanisms that serve to commodify the risks associated with flooding;
Framing and communication: the use of specific terminologies, mental models and discourses as resources to describe and communicate flood risk to professionals and the public.

TABLE 2 Interview questions

What have been the primary sources of innovation in flood risk management (FRM)?
Please identify three key innovations that on your experience have had the most impact on FRM, and why.
Was there a single principal source for these innovations or a network/collective?
Which organisations, in your experience, were important in the processes of innovation? How did they interact with others/each other to influence the processes of innovation?
Certain 'Institutions' may also have been involved. Could you comment on the role of these 'institutions', and their interactions, in the processes of innovation: • Laws • Rules • Norms • Values
What was the role of learning in the innovation processes, and how did that learning come about?
In your experience, what inhibits the process of FRM innovation from happening, or it being of limited effectiveness?
A pilot of this survey identified five 'Avenues of Innovation' (i.e., directions of travel) that have been important for FRM innovation processes: • Measures to tackle the problem • IT/modelling/data gathering • Governance/politics • Resources/finance/skills, etc. • Framing/language, etc.Can you comment on this and suggest what might be missing?

TABLE 3 Our interviewees and their positions/roles (cited with square parentheses in the text)

Interviewee number	Description of position
1	Leading flood risk management (FRM) researcher/academic
2	Director of leading research/consultancy company
3	Senior central government civil servant (Defra)
4	Research manager (retired)
5	Research manager (Environment Agency)
6	Senior Deputy Director (Environment Agency)
7	Senior FRM Engineer active in the 1990s (now living abroad)
8	Senior civil servant (Defra)
9	Member of staff with an innovation role (Environment Agency)
10	Research manager (Environment Agency)

cover the whole field of FRM with our fifteen examples or explore the detail processes therein. This would warrant further research, perhaps using the OECD's 'firm level' methodology.

4 | AVENUE 1: FRAMING, COMMUNICATION AND INNOVATION

We could start our analysis here with any of the five avenues. We begin with this avenue for no better reason than our view that how FRM is framed – the risks, the issues, the solutions and what elements are emphasised and prioritised – defines and gives context to flood risk, both professionally and to the public. The defining and use of flood risk terminologies, phrasing, mental models and frameworks guides discourse and action in FRM policy and planning. How, and even which, issues are communicated is both an innovation unto itself as well as influences the process of other innovation throughout FRM organisations and institutions.

4.1 | Framing, terminology and emphases

The way FRM ideas are framed has changed, often exogenous to FRM itself, acting as a cultural driver for flood risk and innovation. For example, a chief executive supports taking risks, and thereby fosters an innovative culture – '(we are now) told that this is part of what we do' [9][1] – providing a mandate to innovate in otherwise conservative institutions, such as large organisations or government bodies that tend to abide by set guidance, standards and rules [4].

With specific terminology, emphasis has shifted from an engineered approach ('stopping the water!') towards a dialogue of resilience and adaptation ('we can make space for water') (Defra, 2005) [1]. Resilience signifies managing risk to a tolerable level through 'positive notions of recovery and adaptability within an interconnected and unpredictable world' (O'Hare, White, & Connelly, 2016, p. 1176). This is reflected in changes to the 2014 Water Act in the United Kingdom which wrote out 'sustainable' and inserted 'resilience' as a regulatory duty for water utilities [1].

Innovation in communication itself can be risky. For example, the U.K.'s Environment Agency (EA) created an innovative Halloween-themed flood awareness campaign aimed at young people, but the central government's Department for the Environment, Food and Rural Affairs (Defra) rejected most of the spooky graphics as too risky for supporting its investment. The campaign ran with less risky material and was still considered 'hugely successful' [10], but risk aversion remains a factor in communication innovation.

4.2 | Social media and FRM

A key innovation in the last two decades is the use of social media to disseminate and crowdsource FRM information. This has provided the ability to communicate directly with the public to raise awareness and issue warnings in a 'totally different way' [5], passing information back to engineers and planners. This not only generates real-time information but establishes a sense of the public's perception and framing of risk. This two-way form of communication and sharing of context breaks away from the previous top-down information stream. It also encourages a different way of doing things through citizen science and the ability to respond to flood risk with flexibility and mobility. Public opinion and citizen science feedback can be highly innovative and persuasive. Social media facilitates these feedback processes, although the EA so far is 'not particularly innovative in that way' [10].

4.3 | Guidance and innovation

An institutionalised aspect here is 'better availability, and access to, guidance on engineering best practice (for

example)' [4], 'for those not comfortable leading' [3]. Guidance tends come from prominent organisations, showing 'how things should be done' for safety and functionality. It can stymy innovation by supporting the status quo too strongly, or it can promote it by giving 'permission to do things differently' [9].

Guidance in FRM covers a range of activities. It can dictate how to build structures, employ new technologies, plan for long-term risks and undertake rigorous option appraisals. Change to guidance can catalyse innovation, but there is a hesitancy to do so – if there are failures with new approaches, perhaps putting lives at risks, there will be public backlash. Guidance has historically been risk averse, but has the potential to be innovative and introduce new FRM options [5], but this 'can make (staff) uncomfortable' [10].

Guidance 'helps to spread uptake of best practice' and can be 'linked to better informed funding' [4]. The Construction Industry Research and Information Association (CIRIA) has been influential here: '(their) guidance (has been) clearly recognised and accepted by government and the (FRM) industry' [4] and used 'even if it's not proven to the level that they are comfortable with' [2].

4.4 | Within and between avenues of innovation

As indicated above, we emphasise the interaction within and between avenues. Some relevant elements in other avenues are necessarily therefore touched on here. This is to convey that interaction, which is elaborated on further when we discuss the other four avenues in their sections that follow.

Framing, communication and the media therein deployed are interlinked and all have changed the way floods and FRM are conceptualised. Social media has required public-friendly terminology to demystify what previously was the domain of the specialist, breaking down institutional barriers and providing more direct access to policymaking processes and promoting shifts in governance, another avenue discussed below. Institutions and social norms have played a determining role in how risk is re-framed and communicated. Guidance provided by professional bodies has solidified changes in terminology and understanding.

As also indicated above, social media promotes new levels of community engagement, complementing professional and specialist knowledge. The innovative value of another avenue – Information Technologies – cannot be separated from the communication of the results it produces, for example via weather radar on the Internet. How we frame risk also influences the use and innovation of structural measures, which is the second avenue discussed in this paper. The very notion of risk and its communication links to the recognition that flood 'protection' cannot be absolute, leading to the adoption of innovative local measures such as demountable and natural FRM measures to mitigate that risk more holistically. The measures that are now being seen as central to FRM are a function of now normalised engagement and feedback from at-risk communities via social media and other means, demonstrating the web of interconnections both within and between the avenues.

5 | AVENUE 2: INNOVATION REGARDING FRM STRUCTURAL MEASURES

This avenue of innovation embraces a range of structural interventions to reduce flood risk. Traditional FRM relied on engineering measures to reduce flood probability and modify the landscape (Sorensen et al, 2016). Non-structural measures (e.g., spatial planning in flood risk areas; insurance) and their related innovations necessitate a multi-disciplinary approach [7], involving many different organisations and institutions, as encapsulated in our Avenues of Innovation approach. We look again at just three examples.

5.1 | 'Demountables' and property level protection

'Demountables' emerged following the widespread flooding in 2000 (Environment Agency, 2001) with the EA using 'mobile flood barriers as temporary defences' [1]. Previous implementation occurred at Bewdley on the River Severn following the 1998 floods there, when proposed major engineering works were either cost-inefficient or environmentally intrusive. The process by which innovation became realised could be characterised as full-scale trailing. Such mobile flood barriers were 'at first experimental' and are now 'more mainstream'; the 'innovation is spatial' [1], using cost reducing off-site construction [9] and deployment conditional on the approval of local authorities, given their emergency response responsibilities [1].

Similarly, innovative localised approaches have led to the development of property-level protection/resilience (PLP/R) enabling individuals to protect their own homes (National Flood Forum, 2012), supported by 'loads of entrepreneurs in-house protection products' [2]. Barriers to wider uptake of these technologies involve institutional issues of tenure – tenants are at a disadvantage

here (Penning-Rowsell, 2019) – of the need for certification, and support from the insurance industry to incentivise modifying at-risk properties. Further innovation appears necessary here to increase penetration [1].

5.2 | 'Natural' flood risk reduction measures

Recent innovations labelled as 'Natural' FRM measures (NFM) have a more recent history, seeking to use natural processes to channel floodwaters away from urban centres, often by 'slowing the flow' of runoff (Dadson et al., 2017; Lane, Valerie November, Landström, & Whatmore, 2013), partly in response to 'the pressure to deliver multiple outcomes from schemes and not just build concrete' [8]. 'Natural' measures involve 'lots of innovation in natural FRM space'...'combining upstream measures with smaller, cheaper defences downstream' [8] countering a previous 'bias toward the capital intensive approach' but having the disadvantage of requiring greater maintenance in the long run [8].

NFM efficiency is contentious (Dadson et al., 2017), with 'lots going on (but) how far that's proven I am uncertain' [6]. The EA appears reluctant to counter arguments for their further deployment [6], given support for NFM from powerful organisations such as the Royal Society for the Protection of Birds. Adopting some NFM measures was partly driven by guidance from the Institutional of Civil Engineers (ICE, 2001) in legitimising such approaches [4]. Better information has helped: 'New maps show where...opportunities lie for those interventions' [10].

5.3 | Sustainable urban drainage systems ('SUDS')

This innovation reflects the difficulty in many dense urban areas of implementing other flood risk reduction measures through lack of space. 'The major innovation (is) to retain the catchment's natural hydrology and thus not increase its...flood risk regime' [7]. It arose via the implementation of Catchment Planning – a 'deliberately distributed' solution for urban stormwater runoff [7]. Overlaps occur with 'natural' FRM measures, as SUDS's localised swales or small-scale storage ponds are seen as more 'natural' than large-scale engineering structures.

Governance arrangements are complex here. Rules have had to be devised to make developers responsible for storing runoff within their curtilages, with legal powers under the Floods and Water Act 2010. Implementation has been relatively sparse, however, with frequent disagreements about ongoing maintenance responsibilities. 'This innovation was harder to introduce than catchment planning andmanagement, but after some 20 years has found traction all over the world' [7]. When such innovations require ordinance modifications they need 'selling' to the many relevant authorities; 'this is not always an easy task' [7].

5.4 | Within and between avenues of innovation

Again, relevant elements from other avenues that are mentioned here are only elaborated upon later in this paper.

This avenue is characterised by continual change in emphasis amongst FRM organisations and lobbyists concerning the range and type of intervention measures to be implemented and debates about their effectiveness and their use of via laws, rules and norms. Portfolios including a variety of risk reduction methods are now mainstream, indicating that measures are interlinked; in our case SUDS and natural FRM are both elements in a land-based approach to flood risk reduction.

All measures and their appraisal are related to methods of flood risk assessment, hence the interaction between this avenue and that concerned with Information Technologies and the relevant risk data that such technologies can deliver. Many innovative measures, particularly those in urban areas, are influenced by governance arrangements there, while being supported or discouraged by community engagement. The lack of sufficient resources for major flood risk reduction investments can lead to local initiatives: a 'mini-industry' has developed property level protection technologies, forming a dynamic and innovative competitive market, but not always with well-designed and effective products. The implementation and innovation of measures, whether engineered or natural, depends on the financial resources, the governing bodies overseeing the project, the risk framing and incentives, and the technology and data available. All of these influence or inhibit the type and scale of innovation in this avenue and its relation to the others.

6 | AVENUE 3: GOVERNANCE AND POLITICS

A dominant influence on FRM is 'the regulatory structure of how things...get done through a devolved government' where innovations are 'stimulated by regulatory arrangements' and rearrangements [1]. The U.K.'s legal

framework for FRM is an intricate mixture of slowly changing rules and responsibilities. A complex local/national interplay, and its lengthy history (Penning-Rowsell & Johnson, 2015), can perhaps stifle innovation.

6.1 | Devolution

An important innovation since the 1990s has been devolution of FRM responsibilities to Wales and Scotland, and from central government to local agencies and institutions in England. The driver has been a general wish to move power away from London. The acknowledgement of local capacity for FRM comprises one such move.

The result has been innovation in Wales (Welsh Government, 2011) and in Scotland (e.g., Fenn, Daly, Miller, Begg, & Kuik, 2015), with Scottish legislation mandating the adoption of natural FRM measures (Dadson et al., 2017). In England, key responsibilities have been devolved to Lead Local Authorities under the Floods and Water Management Act (2010).

These Authorities have had to develop Surface Water Management Plans (Defra, 2010) and increase their skills base. With repeated flooding since 2000 'there was no way (the EA) could have solved all the issues; they needed support from other agencies and local authorities' [8]. While innovative, a principal concern continues to be whether these local authorities have the capacity, skills and funding to deal effectively with the risks that they face.

6.2 | State and private-sector suppliers

Quite a different innovation concerns the evolving relationship between state and commercial organisations within the FRM field. The EA and Lead Local Authorities purchase large amounts of goods and services from the private sector. Innovation is common as 'most of our work is delivered by our framework suppliers and their supply chain' [9] in constructing flood defences, but also assembling data, producing research and developing public engagement information and skills.

There are pressures on suppliers to reduce costs, perhaps by innovative use of non-conventional methods and techniques. Competition here incentivises suppliers to be different, and 'a lot of innovation in project(s) comes from those...supply chains' [9] and through contract bidding. The more competitive the process, the more incentive to innovate is created [6] and 'a lot of innovation occurs on a contract by contract level' [5].

Organisational changes are continuous, and in 2018 the Agency initiated a system of prime providers, with competitive tendering for those roles, and new procurement rules. The new systems 'seem to have a good understanding of human behaviours' [6], and are intended as 'an arrangement whereby innovation...is mandated to be shared across all FRM providers, rather than retained as private intellectual property by those creating that innovation', getting away from 'the previous element of lock-in' [6].

6.3 | Community engagement

Our third example here is the more systematic and purposeful approach to community engagement in FRM that has evolved over the last 20 years (Environment Agency, 2009a, 2009b) and is now 'taken for granted' [3].

This innovation stems from 'a need to address local needs through locally-specific creativity' [10], and from 'communities...passing on good quality information' [4], both bringing about and employing organisational change (Fenn et al., 2015). 'We (the Environment Agency) have extensive networks of flood wardens, flood groups...there is lots of innovation in...how they sustain (their)...engagement' [10].

The Flood Resilience Community Pathfinder scheme is a further example here (Defra, 2015). The aim was innovative local solutions that enhance FRM and awareness in ways which quantifiably improve a community's overall resilience to flooding. The Pathfinder projects 'created lots of flood groups and made them meet and exchange ideas, which was highly successful...but quite a challenge because (such engagement is) resource heavy' [10].

6.4 | Interactions within and between avenues

Governance arrangements and the locus of power have a significant influence on all other avenues. There are clear interactions between devolution and innovation via community engagement. Both are part of a 'localisation' of FRM; a politically inspired move away from centralised control as evidenced by the domination of the EA and Defra/MAFF until the beginnings of the 21st century, and the decline of agricultural interests (Penning-Rowsell & Johnson, 2015; Tunstall, Johnson, & Penning Rowsell, 2004).

The increased role of the Meteorological Office since 2000 reflects innovation in weather radar technologies in flood forecasting for specific localities, previously very limited. The devolution of responsibility to local levels, particularly to local authorities, is linked to the innovative use of 'demountable' flood defences and SUDS. Local

authorities' spatial planning roles can impose SUDS requirements on developers, impossible when virtually all FRM was the responsibility of the EA.

Innovation in the use of social media in flood events has helped the involvement of communities and their champions in FRM decisions. Open data sources now available to the public also facilitate that engagement by allowing community assessments of risk, to be followed by community suggestions for risk reduction. As elsewhere in society, access to information brings power and influence, at least to some degree.

7 | AVENUE 4: FINANCE AND RESOURCES

This avenue includes all the financial resources and arrangements that influence, fund or control FRM. Innovation has been significant in the last two or three decades, largely driven by initiatives from central government. We again examine just three examples.

7.1 | 'Partnership funding'

FRM is capital-intensive. Most risk reduction is related to investment, with a 'direct line between policy and investment as to what kind of innovation happens' [10]. A major innovation since 2011 has used the concept of what is termed 'cost-sharing' in many other countries.

'Partnership funding' was initiated by Defra (2011), driven by a squeeze on public expenditure given the 2007 worldwide financial crisis. Capital grants from central government, using taxpayer sourced resources, are complemented by finance from the at-risk locations, as 'beneficiary pays' contributions. The 'lack of public funds made it clear that it wasn't possible for the government to pay for every FRM intervention and there had to be a change' [8].

One consequence of this innovation is that many local communities have engaged more in scheme development, aware that local contributions would be necessary. This was the 'innovative bit': more decisions were shifted back to the local level, 'turning this around' [3] and giving more people a stake in the result [3]. It has not yet 'changed the nature of the schemes; innovation will take time' [3].

7.2 | Flood Re and its new flood insurance model

Widespread flood insurance in the United Kingdom, originating from the 1960s (Penning-Rowsell & Johnson, 2015; Penning-Rowsell, Priest, & Johnson, 2014) serves to commodify flood risks. A series of agreements between insurers and the government made standard household insurance available from private insurance companies to all who wish to buy it (Lamond, Proverbs, & Hammond, 2009). The various arrangements, as they evolved, have involved repeated cross-subsidisation and a lack of premium adjustments to properly reflect risk [1].

Launched in 2016, Flood Re replaces the pre-existing schemes and aims to keep insurance affordable for households in at-risk areas – a key government aim. It is a unique scheme, the first of its kind anywhere in the world (ABI, 2015),[2] with a challenging lifetime of only 25 years until premiums are meant to be fully risk-reflective. An insurance company levy creates a pooled resource used to reduce otherwise high premiums (ABI, 2015). This innovation was driven by a combination of government concern about insurance affordability and insurer concern that newcomers in the market could gain competitive advantage over the established companies by not being party to the previous government/insurer agreements.

7.3 | Efficiency targets

'This is a high profile driver (of innovation)' [9]. All public sector U.K. infrastructure investment must follow strict government rules ensuring all options are considered and investment is economically efficient (HM Treasury, 2018). Starting in 1999, a series of Project Appraisal Guidance documents codified these arrangements for FRM, directing the economic assessment of major capital schemes (MAFF, 1999): 'a major spur (to innovation)' [4]. A series of Output Measures have since guided decisions towards reducing the flood risk to residential properties, particularly those in low-income areas, and those providing environmental enhancements (Penning-Rowsell & Pardoe, 2015).

These innovations sought multiple outcomes from schemes and reflected 'pressure (for) cost reduction on suppliers to public sector (projects)' [1] and to 'meet an efficiency target – say (a) 10% (cost) reduction' [9], 'spurred on by (requiring) doing more with less' [3]. They were to make explicit that 'If we spend public money we must be confident on the outcome' [8]. Appraisal for FRM practitioners is 'a tiresome ritual' but successive governments have been trying through its evolving processes 'to be working (out) what is the best thing to do' [3].

7.4 | Within and between avenues

The partnership funding system is complemented by efficiency targets designed to both raise more money from

local communities and spend it efficiently to obtain agreed outcomes. The government's insistence that the insurance industry provides affordable flood insurance reflects a growing reality that the available grant aid through the partnership funding system cannot tackle the majority of flood risk the country faces. Innovations creating the partnership funding and Flood Re arrangements therefore sit neatly side-by-side to tackle both the economically viable construction schemes and the residual risk.

Between avenues, resources and governance arrangements are intertwined. Resources from the government are often steered by politics and how it spends public money is influenced by how they frame their priorities and the extant governance arrangements. The innovation behind partnership funding is at least partly designed to promote community engagement, and the development of those closely monitored efficiency targets complements the competitive tendering for the implementation of risk reduction measures and the cost savings that should result. Whilst there is devolution of governance responsibility for FRM, the 'rules of the game' concerning resources and their use remain unambiguously tied to central government priorities and their political determination (Penning-Rowsell & Johnson, 2015).

8 | AVENUE 5: INFORMATION TECHNOLOGIES

The last 30 years have witnessed a massive transformation in the use and the variety of information technologies available in FRM, as in many other fields. Innovation has been widespread and rapid, facilitated by massive increases in computing power and communication facilities including the internet. The driving forces – much fundamentally exogenous to FRM – have included intense competition between technology providers and a profound dissatisfaction in the FRM community with previous methods and the uncertainties that they created.

8.1 | Remote sensing data acquisition

Innovation in airborne remote sensing and the resulting better ground elevation data using high resolution LIDAR has 'improved (the) spatial modelling of flooding and flood risk' [4] and removed 'a huge amount of uncertainty' [5], feeding 'into policy, and into (better) planning of flood risk and asset management' [4].

One example of innovation here was when the EA discovered a high rate of failure in flood defense infrastructure at what they call transition points. LIDAR and 'a whole suite of different data' pinpointed where those transitions were hidden [10], providing a more realistic 'prediction of defense failure and overtopping' [4] thereby the 'enabling of (further) innovation' [9].

Drones can be used to monitor the evolution of flood events in real time [6], solving the previously problematic use of aircraft owing to the generally unfavourable weather conditions during such events. They are also involved in mapping and defining catchments to understand and model 'the way water moves around the catchment' [3]. The digital revolution that this represents is 'leading to different thinking and framing (of) problems' [9], and spurs collaboration between different organisations, such as flood agencies and telecoms companies.

8.2 | Weather radar for flood forecasting

Weather radar has developed very substantially over the last two decades. Its results are now available for members of the public free of charge, through the Meteorological Office (2019) website 'getting people more actively involved in floods response' [4]. Government funded meteorological science has been a crucial driver here (Freebairn & Zillman, 2002; Hunt, 2013).

Flood-generating storms can now be seen for the United Kingdom in real-time, with step changes of only five minutes, enabling the tracking of extreme events as well as warnings of rain-affected cricket matches or picnics. "Wider availability (of) real-time weather radar – leads into better flood prediction, in particular with the more localised intense rainstorms now being experienced" [4], facilitating "our ability to rapidly forecast" [10].

The innovation was, again, exogenous to FRM but flood-affected communities gain information, and trust is created as the innovation cascades down to the public at large. Such 'open data' leads to greater collaboration, invention and ability within FRM, expanding the capability of what can be achieved [10].

8.3 | Mathematical hydraulic modelling

The hydrodynamic mathematical modelling of flood flows – now routine but highly innovative in the 1980s – 'provide a logical and mathematically rigorous framework for compiling information to estimate flood risk' (Castillo-Rodríguez, Escuder-Bueno, Altarejos-García, & Serrano-Lombillo, 2014, p. 380) and for developing effective and efficient flood risk reduction measures [1]. Coupled with more accurate digital terrain models of the floodplain, both driven and facilitated by hugely faster

computing [3], this modelling has 'enabled the effects of differing options to be assessed' [7] routinely in ways that was impossible before.

A driving force here in the 1980s/1990s for incremental model improvements was competition to provide public agencies with better models between HR Wallingford (previously specialising in physical models) and the Halcrow Group (now Jacobs), a private civil engineering company. The far lower costs of mathematical modelling compared with physical modelling [7] also drove the innovation (Bates, 2005), in an environment of competitive tendering, as well as the former's ability easily to investigate multiple scenarios rather than single situations.

8.4 | Within and between avenues

Within this avenue, innovation is related to massively increased data handling powers with modern computing. Each individual innovation, be it remote sensing, weather radar or mathematical modelling, has been developed owing to collective learning within the FRM community as to the potential of these technologies to deliver new insights and also to manage their burgeoning computational and data storage requirements.

These advancements have hugely increased our ability to evaluate different flood risk reduction measures. Furthermore 'the digital transformation agenda has shown the need to think differently and work with different people, suppliers, etc. to improve capability to produce (new) tools' [9]. Community engagement has been facilitated by open data sources and user-friendly modelling programs. Social media use in flood situations would be impossible without these information technology developments. There is hardly another avenue of innovation as described in this paper that has not been affected by information technology development, leading to and following higher and higher expectations amongst professionals and the public as to what can be understood about the nature of flooding and the effectiveness of risk reducing measures.

9 | FACTORS INHIBITING INNOVATION

An understanding of the interdependence within a system of innovation can help identify 'leverage points' in order to enhance innovative processes and also 'pinpoint mismatches within the system, which can thwart technology development and innovation' (OECD, 1997, p. 14).

Our interviewees were asked to consider what factors might be thwarting or discouraging innovation (Tables 2 and 4). What is notable is that the majority of these factors concern managerial aspects of the major organisations they had experienced and the characteristics of the staff employed there. Large organisations clearly have to have rules of conduct and processes of operation, necessary 'to keep a lid on things' [3]. But such systems generally appear inevitably to stifle creativity and innovation ('Creative people work outside rules' [3]).

Funding issues can also play a significant role here. Too much capital can lead to complacency and a lack of creativity [2], while too little results in risk aversion in avoiding solutions that may fail [1] or had not yet been validated by guidance [5]. Inter-organisational issues, such as contracts for procurement, also can have unintended consequences by restricting access to new methods or similar innovations [6]. Competitive tendering can foster innovation, but when it is done in isolation, it can prevent a new method or technology from becoming mainstream and verified through guidance, engineering protocols or some other validating standard, upon which the U.K. FRM industry still relies heavily [9].

Lessening the impact of these inhibiting factors might be mainly a question of organisational change, or changes to training and advancement routes, or a change in attitudes of senior management towards risk-taking. The context is that substantial investment has occurred in U.K. FRM over the last two or three decades, and the public health and wellbeing impacts of any failures would be substantial. Inertia or lack of innovation is at least partly the result of the massive potential repercussions of an error of judgement. Hence people and organisations tend to move incrementally and cautiously. There is clearly a danger, therefore, that accountability for the use of public funds – dominant in U.K. FRM – leads to a conservative and risk-averse approach [8] (Table 4). This is a problem that needs attention, but a solution appears far from easily obtained.

10 | RECOMMENDATIONS

A compilation of recommendations for FRM professionals to better promote innovation in FRM emerged from the interviews. While innovation is not an exact science, there is a variety of strategies – enacted alone or in tandem – that can help foster greater innovation throughout a system.

10.1 | Innovation Champions

The concept of an innovation champion was widely heralded by interviewees as an effective or necessary

TABLE 4 Factors seen as inhibiting innovation by our interviewees, identified via a comprehensive codification of their responses (see Table 2, question 7)

Inhibiting factor	Elaboration	Quotations from interviewees
Rules, processes or guidance	The presence of rules or other arrangements such as guidance can inhibit creativity by restricting practices to those that are 'tried and tested.'	'Absolute adherence to rules can never be creative' [3]. 'Change in guidance can make people feel uncomfortable' [10]. Blame: the accusation of 'What have you done?; you haven't followed the guidance/standards' [9]. 'If we spend public money we must be confident on the outcome' [8].
Risk appetite and senior level support	Most flood risk management (FRM) is undertaken in large organisations which tend to be risk-averse. Innovation is stifled when not supported by senior staff in positions of managerial authority.	'We are inherently a risk-averse organisation... (Staff) always resorting to the things that they know will work' [5]. 'Lack of support from senior management [7].' '...people getting stamped upon because they are out of court' [2].
Education and training	Much FRM is still dominated by engineering methods. Several interviewees suggested that training here is (unnecessarily) conservative.	'Many...(engineers) are unable to depart from established practice within their organisations' [4]. 'It is fully engrained in engineering approach(es) and philosophy: this fear of failure' [5].
Competitive procurement	Contracts for procurement of public sector FRM components (structures; plans; consultations; etc) are almost invariably by competitive tendering. Innovative elements are often retained by the tenderer rather than disseminated more widely.	'Competitive tendering has a tendency to produce great innovation(s) but then to prevent them from being shared' [6].
Available funding and resources	The availability of resources for a particular FRM activity may encourage complacency.	'Too much money (means) they have the money to do it as before (rather than differently)' [2]. 'The main pressure is cost reduction to (the) public sector: (a) stimulant to innovation up to a point, but then becomes unproductive and actually inhibits innovation' [1].

component to catalysing, managing or introducing innovation in FRM. Champions are central to sharing information and shedding light on processes, whether across teams, projects or supplier organisations [9]. They connect people, ideas and lessons learned in a catalytic way; they not only promote learning but act as a conduit, taking underdeveloped ideas to fruition across avenues [8, 9]. They provide vision, motivation and perspective and are able to extract and share lessons across a system. Champions are able to galvanise a network of people around them through 'really strong partnerships and a range of people to solve [the problem]' [9].

Nothing innovative can be systemically achieved without people promoting innovation; it 'doesn't happen without someone agreeing to champion it' [10]. The concept of a champion materialised in some form in every interview, suggesting it is a crosscutting component, perhaps sitting 'above' all the avenues, instead of permeating across them. The champion is at once an enthusiast, a promoter and a driver of innovation, 'overcome[ing] roadblocks experienced' [7]. We are not suggesting that a champion is the sole component necessary toward greater innovation in FRM, or that some champions do not hold their innovations to themselves or their teams without sharing them widely, but rather that they are generally necessary to catalyse innovation across the system.

10.2 | Risk culture

A low appetite for risk stifles innovation, as demonstrated above. This stems from a culture of risk aversion that demands permission, mandates and guidance before any sort of risk-taking (i.e., a new way of doing something).

Cultural drivers of risk act as a guiding hand over innovation in FRM. Top-down attitudes permeate across systems and sectors, either stifling or promoting innovation and related failures and successes [6]. Positive statements and a mandate of 'this [innovation] is what we do' inherently grants permission to try new things [9]. This can result in people 'think[ing] outside the box a bit, as the measure may not be in the discipline that they thought' [2]. Moving from a culture focused on precedent, rules and guidance to a culture of permission shifts the institutional inertia around innovation. It is important to be diligent, as lives and resources are at stake, but organisations 'have to accept that things will go wrong' in order to create better outcomes [5]. Creating a culture that encourages innovation can involve both 'throwing people in the deep' [7] and a more organised approach of 'knowing how the task is traditionally done and having the curiosity to consider different approaches and experiment with them in a risk-free, enabling environment' [7].

A fear of failure, and a fear of risk, will only reinforce the same cycles, systems and strategies as before. We believe that changing top-down attitudes, culture and values toward accepting failure and taking risks related to FRM will usher in greater creativity, stronger partnerships and productive curiosity.

10.3 | Learning

Learning is essential to innovation. It 'is massively important; you have to be prepared to try things out' [2]. Learning is both a process and a product – the process of acquiring new knowledge and ways of doing things and the lessons learned delivered as guidance, standards and other mechanisms, which can institutionalise that learning and innovation as a new status quo.

Learning has long been part of the innovation process – 'things now taken for granted, such as involving the community and environmental economics, have been learnt' [3]. Bringing people 'back to the table' to learn these processes, however simple or inherent they may seem, 'is important' [3]. There is a tendency to 'consider researching things already well-understood' [2]. A systems-thinking approach to learning 'forces you to think of things you hadn't before by highlighting gaps and thinking about things that are difficult' [2]. People do not change their behaviour, or systems, through products; they change it by learning [10]. Roles that facilitate learning, such as flood wardens or volunteers, are important – 'peer to peer learning is highly successful' [10].

Learning occurs both top-down – professional bodies, institutions and governments all have active programs, lectures and workshops 'ensuring that professionals are as up-to-date as can be' [5] – and bottom-up, through crowd sourcing, peer exchange and community-level training [7, 10]. Attitudes toward learning matter. Being able to recognise 'what you don't know, the "known unknowns"' fosters greater learning and recruitment within organisations [5]. One interviewee noted that you can sense an organiation is 'getting stale when recruitment is low', signifying the organisation is not learning and growing [5]. Our view is that while learning is not the easiest to record or quantify, its role in and effects on innovation are indisputable.

10.4 | Scaling Innovation

Innovation must be scaled up, out and across systems in order to be sustainable and effective long-term. This involves communities and stakeholders working across disciplines.

Scale itself can be innovative; 'whether it is point-based, location-based, town-based, catchment-based, United Kingdom-based; you can be quite innovative in how you use that scale' [10]. The 'use of measures in one (scale) influence how it is used in another place', [10] showing how scale can work across systems. Interventions can happen on a variety of scales; 'something happening in one place and then helps it happen somewhere else' [10]. Locally-derived innovation typically arises to address a singular, local need, and 'then it pops out to all over the country' [10].

Scaling innovation is still a challenge; people 'are not very agile' as scalers of innovation [10]. Ideally, we should be able to see innovation 'at every level of the FRM landscape: policy, technology, how you engage with communities, and how information is communicated' [8]. Scaling requires a 'willingness to explore gaps between disciplines, such as the interface between engineering and the environment' [2]. The pathway to innovation implementation 'is often shorter when you are working on a national solution and try to make the method work on multiple scales' [5]. Considering the scale of the innovation, as well as being flexible and trusting enough to allow for creativity, allows the innovation to be more responsive, sustainable, and effective.

11 | CONCLUSIONS

The research reported here aims to foreground the need to better understand and promote innovation in U.K. FRM and the benefits that can result. We also hope to add to the innovation literature by examining this

hitherto neglected and complex multi-disciplinary field. Lessons learnt here may be useful elsewhere.

What we see is that innovation here occurs incrementally at different paces and in different ways, and at numerous scales. It is almost entirely unplanned, often overlooked and almost never researched. Sources of research funding for FRM appear not to be ensuring that innovation itself is promoted.

The 'Systems of Innovation' method – used here within what we term 'Avenues of Innovation' – reinforces the interconnectedness and non-linearity of innovation across the FRM system, as illustrated by our fifteen examples and the contributions from our ten interviewees. Drivers of innovation are both endogenous and exogenous to that system, involving complex networking and lay involvement. FRM professionals need to recognise that institutional and organisational issues inhibit innovative progress.

To counter these inhibiting effects, innovation champions need promotion and risk-averse cultures need to be stymied. Learning needs further encouragement. More also needs to be discovered regarding detailed facilitating processes, so as to strengthen them and add to their gains. In this way innovation needs to be better institutionalised and 'built-in', rather than being simply left to chance.

ENDNOTES

[1] These square parenthesis all relate to interviewee numbers (see Table 3)

[2] https://www.abi.org.uk/products-and-issues/topics-and-issues/flood-re/flood-re-explained/Incentives.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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